

Beauty and Charm at CDF

Using the Hadronic Trigger

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Lunch Meeting
October 9, 2003

Outline

My main physics interest

- + contribute to solution of matter/antimatter puzzle
- + tests of the Standard Model with b hadrons
- + find new physics with b hadron decays

Experimental setup

- + Tevatron accelerator
- + CDF detector

Status and first results

- + masses and lifetimes
- + mixing
- + a new narrow state

The *CP* Puzzle and the *CKM* Matrix

Matter/Antimatter asymmetry

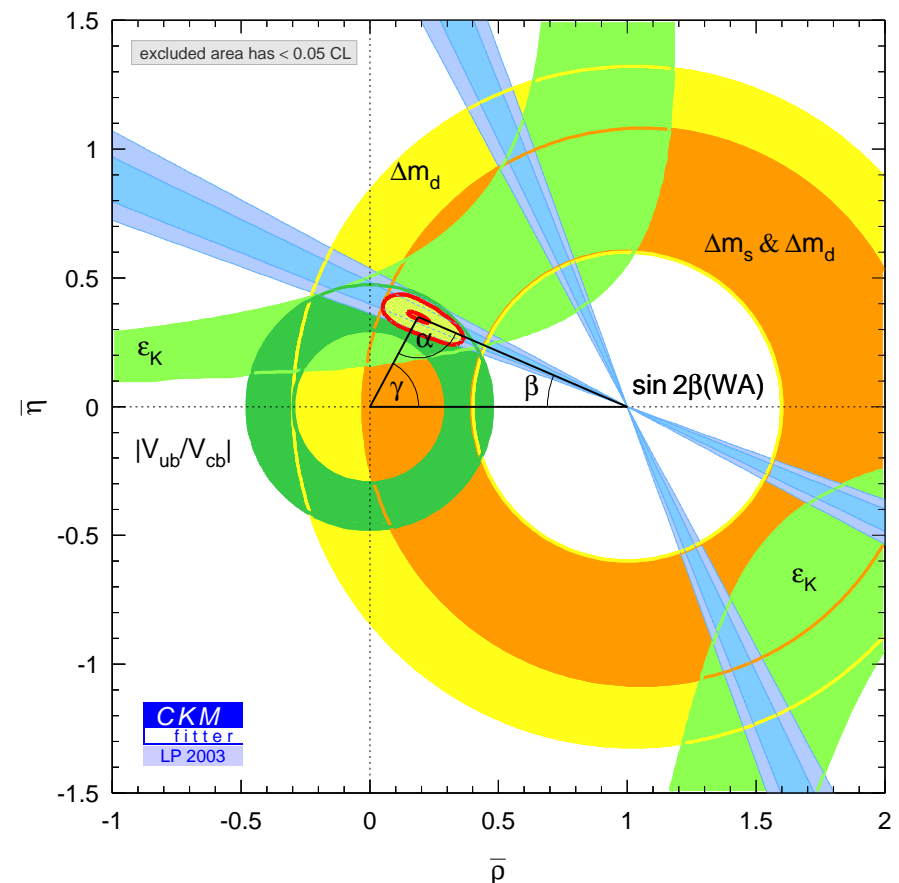
- + why so much matter?
- + Sakharov says:
CP must be violated
- + *CKM* matrix describes *CP* violation in SM
- + amount too small to explain matter/antimatter asymmetry
- + good spot for new physics

Measure *CKM* components

- + unitarity condition $VV^\dagger = 1$
- + derive unitarity triangle

Sakharov's Conditions (1966)

- + proton must decay
- + universe had a thermal non-equilibrium phase
- + *CP* must be violated



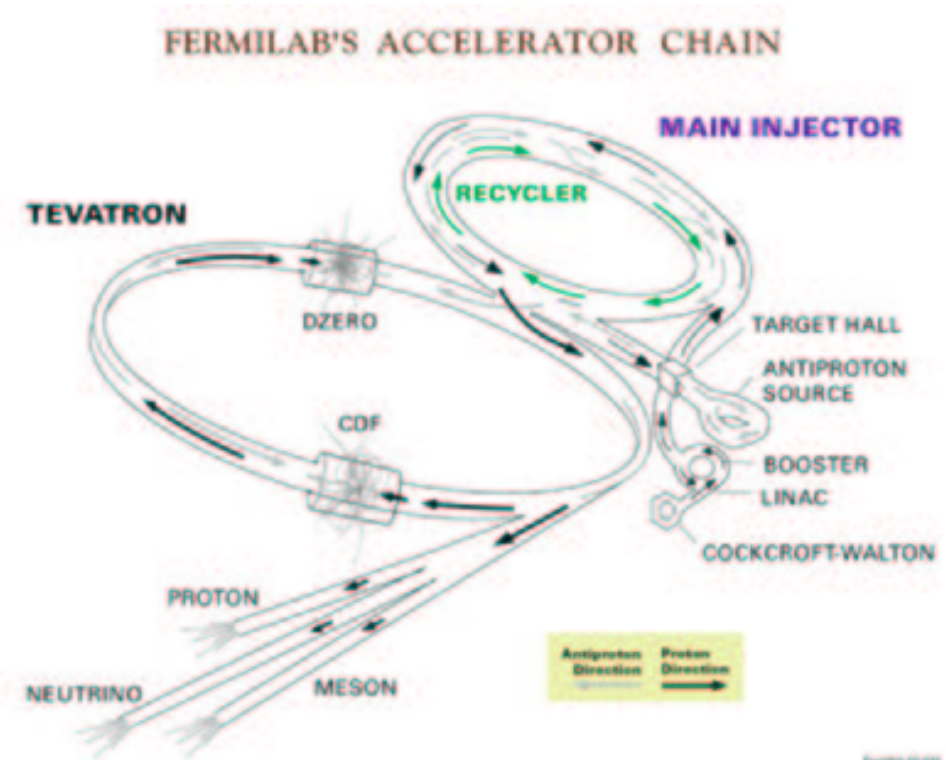
Tevatron Upgrade

Main injector

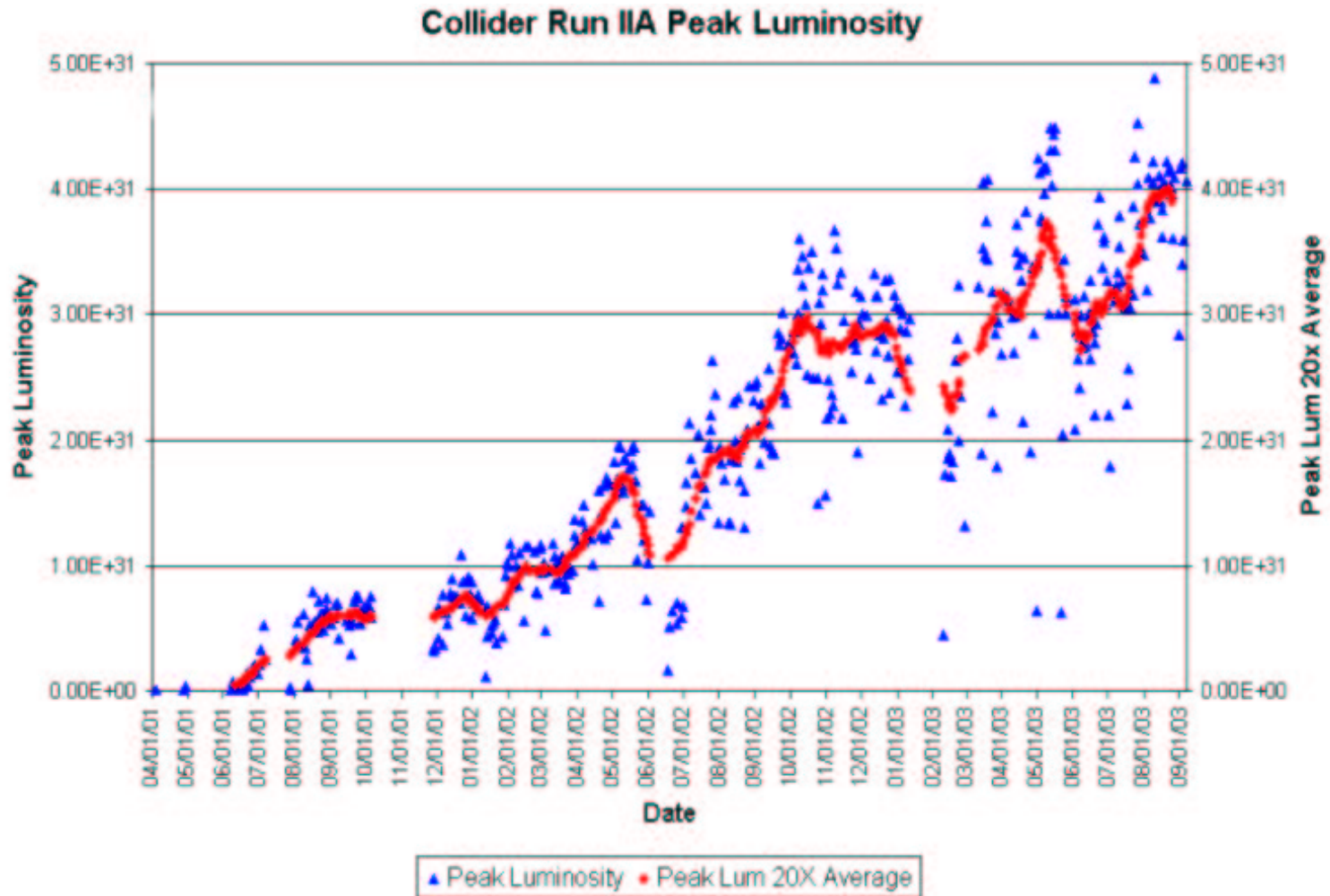
- + new Tevatron injection stage
- + accelerate and deliver higher intensity of protons
- + more efficient \bar{p} transfer
- + \bar{p} recycler (in progress)

Overall improvements:

- + higher collision rate: 396 ns (36×36 bunches)
→ 5-10 higher instantaneous luminosity than Run I
- + higher center-of-mass energy
Run I – 1.8 TeV → Run II – 1.96 TeV



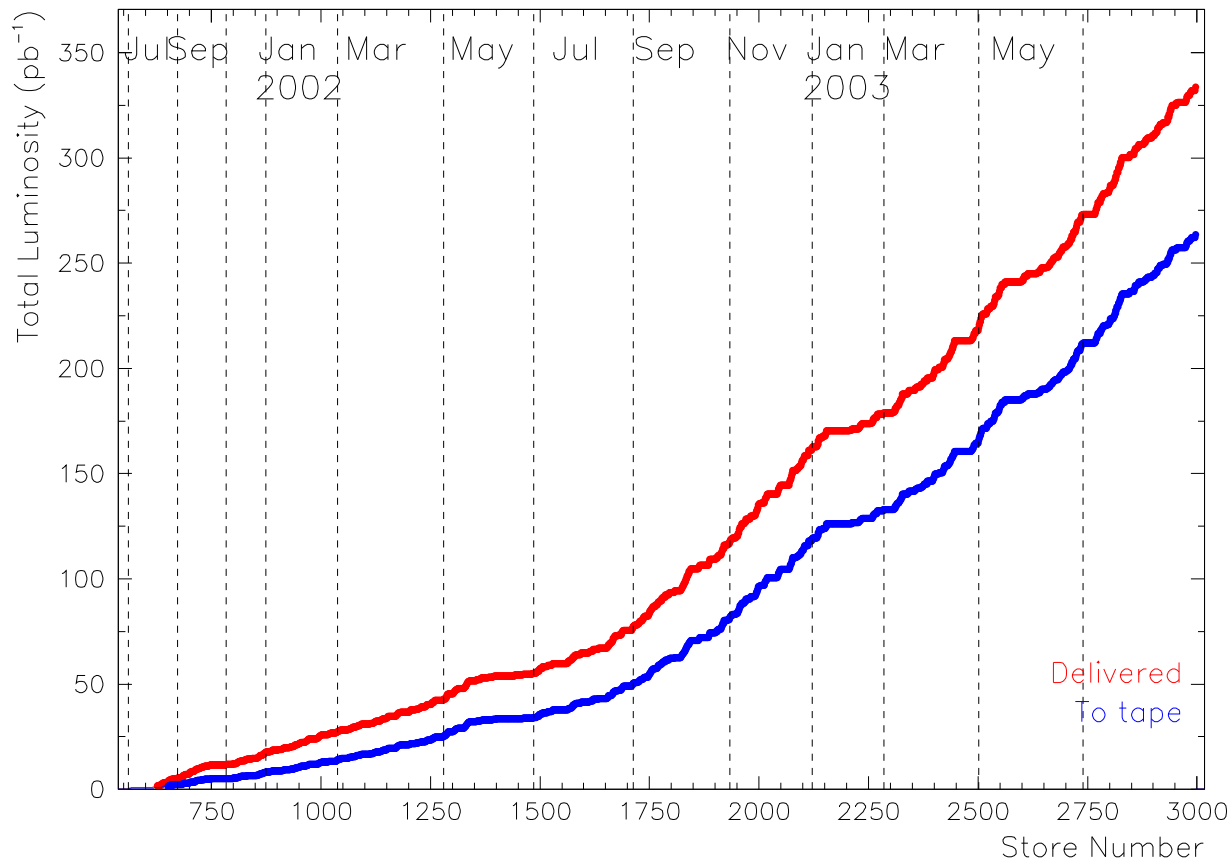
Performance: Instantaneous Luminosity



Accelerator Performance

- + record: $4.8 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
- + below expectations by about factor of 2(4)
- + improving slowly, 4-7 pb^{-1} per week

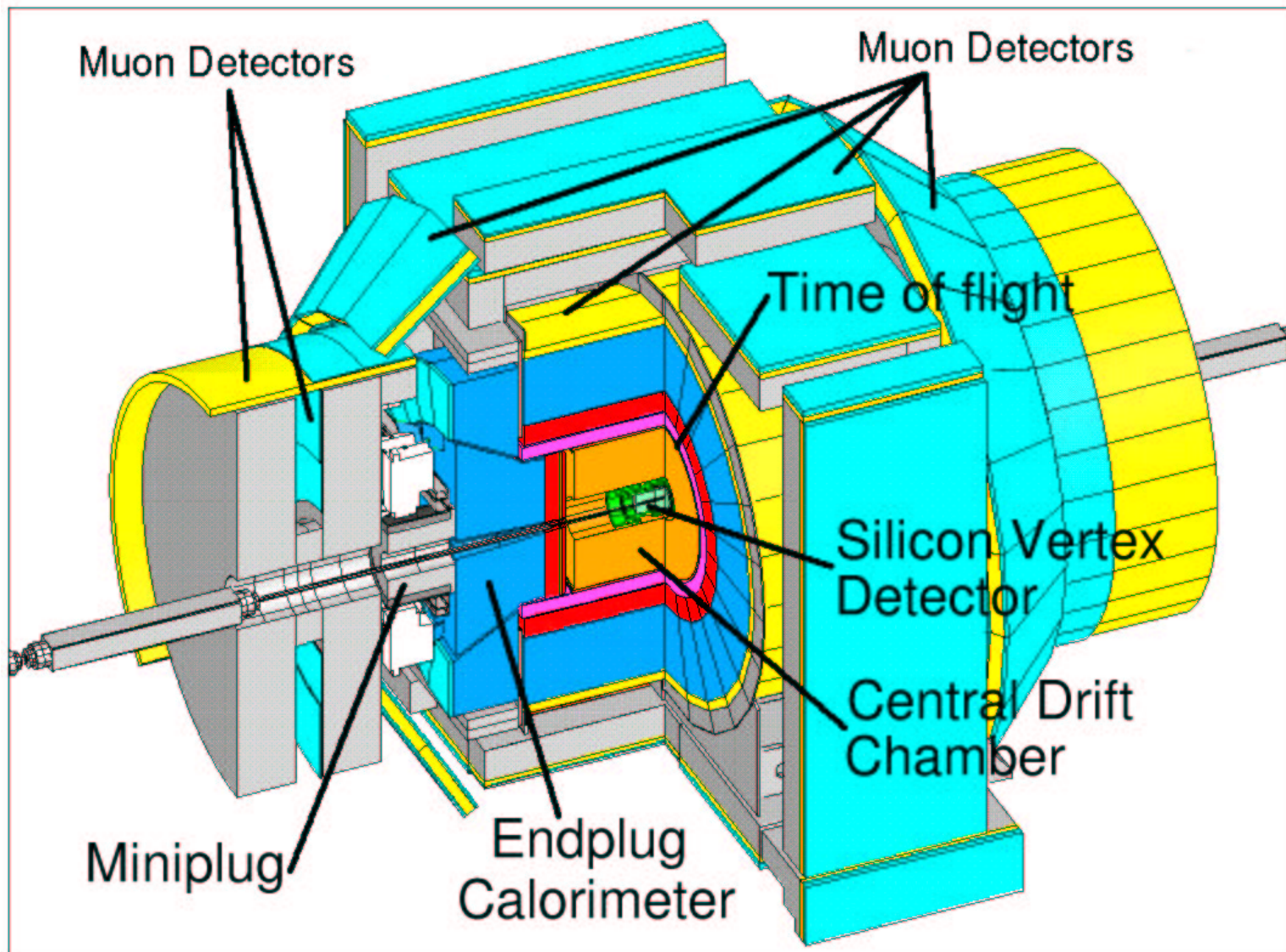
Performance: Data Taking



For CDF:

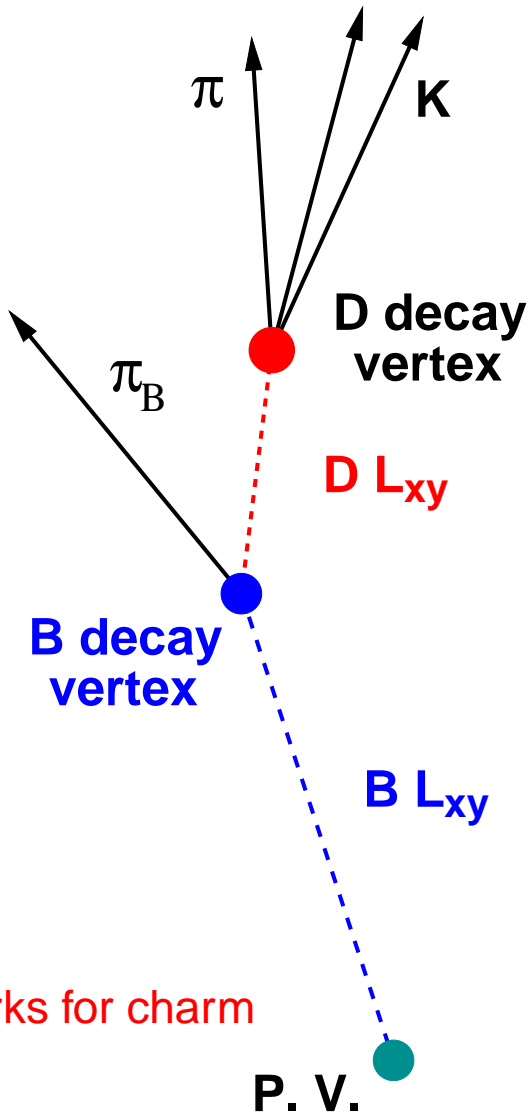
- + Current 330 pb⁻¹, 260 pb⁻¹ to tape
- + For analysis 280 pb⁻¹, 220 pb⁻¹ to tape
- + ≈ 200 pb⁻¹ with all important systems on
- + 120 – 200 pb⁻¹ used for analyses shown in following

CDF II Detector



Run II Upgrades: Hadronic Trigger

Run I: only e, μ trigger

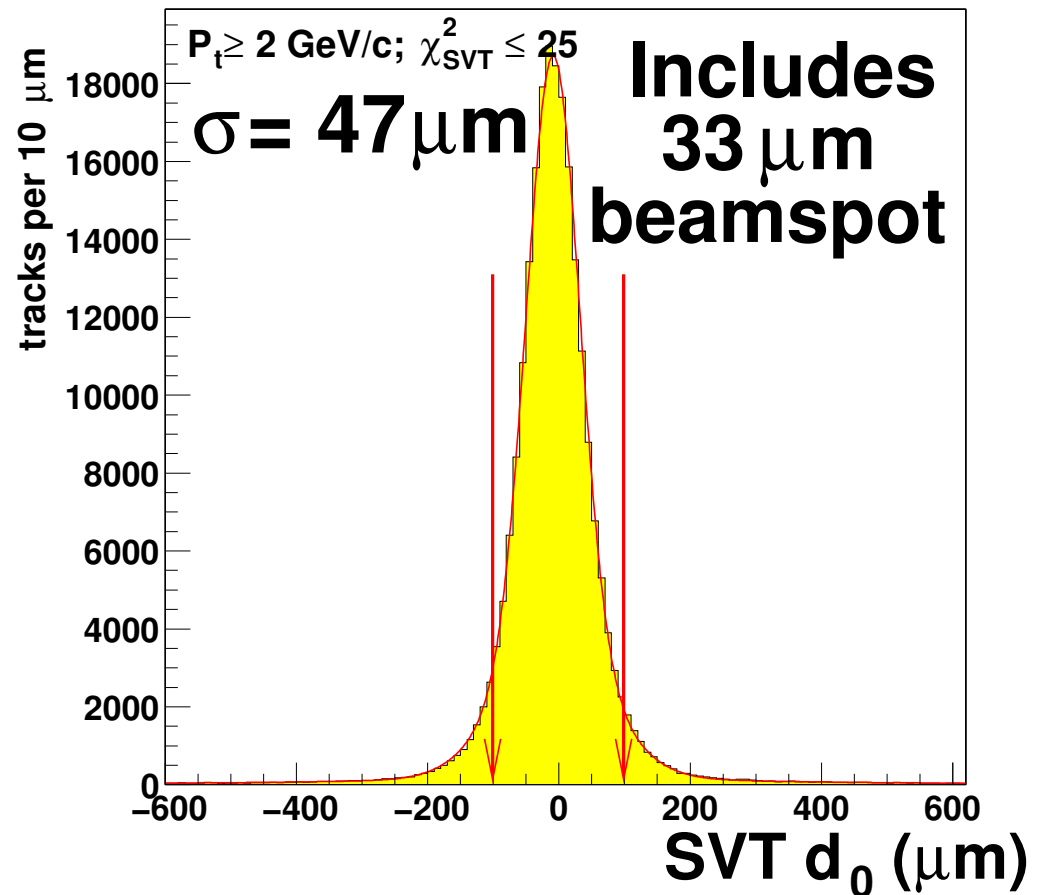


Also works for charm

Level1 track trigger: high p_T

Level2 track trigger: large d_0

Improves Run I sensitivity by 4-5 orders of magnitude



Bottom/Charm Production in $p\bar{p}$

Compare $\sigma(b\bar{b})$:

$\Upsilon(4S) \approx 1 \text{ nb}$ (only B^0, B^+)

$Z^0 \approx 7 \text{ nb}$

$p\bar{p} \approx 100 \mu\text{b}$

Light quark $\sigma(\text{inelastic})$ 10^3 larger

at $p\bar{p}$ it is all about the trigger

Run I: $B^+ \rightarrow J/\psi K^+$ ($p_T > 6 \text{ GeV}, |Y| < 1$)

+ single inclusive (B^+): $3.6 \pm 0.6 \mu\text{b}$

+ Peterson fragmentation:

$$\epsilon_b = 0.006 \pm 0.002$$

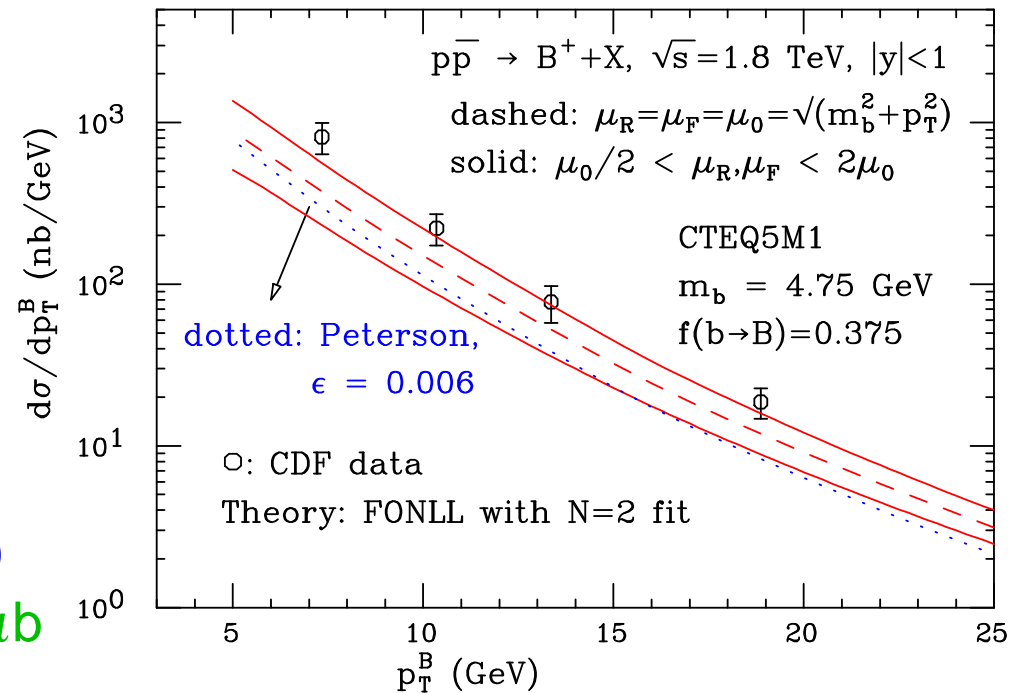
+ $\sigma_{\text{data}}/\sigma_{\text{theory}} = 2.9$

Run II: $D^+ \rightarrow K\pi\pi$ ($p_T > 6 \text{ GeV}, |Y| < 1$)

+ single inclusive (D^+): $4.3 \pm 0.7 \mu\text{b}$

Run II: $D^0 \rightarrow K\pi$ ($p_T > 6 \text{ GeV}, |Y| < 1$)

+ single inclusive (D^0): $9.3 \pm 1.1 \mu\text{b}$

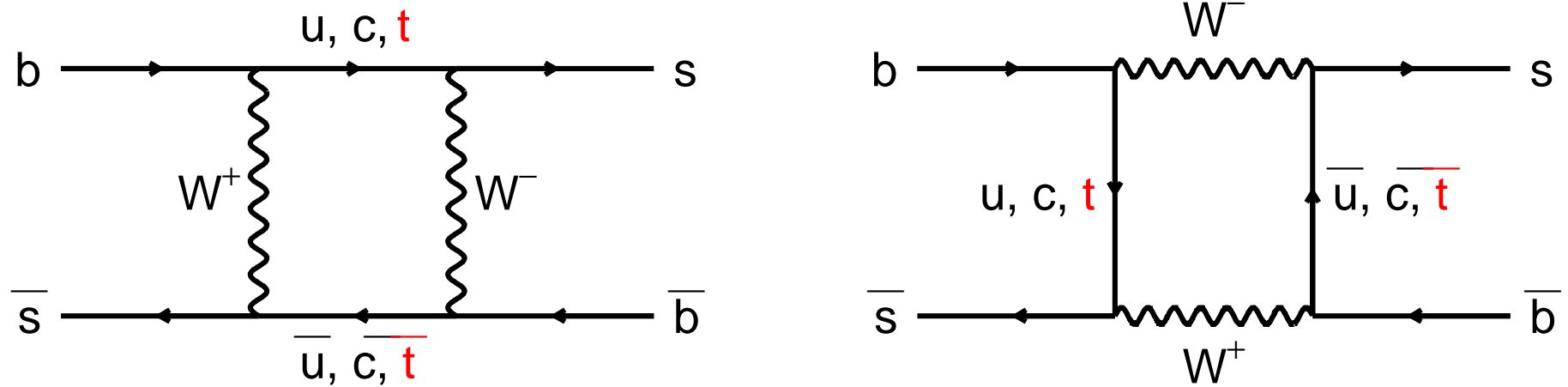


Updated theory bottom production

- + Peterson fragm. tuned for LL
- + different parameter: $\epsilon_b = 0.002$
- + better even different fragm.
- + theory update FONLL Cacciari, Nason
- + $\sigma_{\text{data}}/\sigma_{\text{theory}} = 1.7$
- + data do not contradict theory

Quark Mixing for B Mesons

Feynman diagram of B mixing



Probability densities for B -meson mixing:

$$P(t)_{B^0 \rightarrow \bar{B}^0} = \frac{1}{2\tau} e^{-t/\tau} (1 - \cos \Delta m t)$$

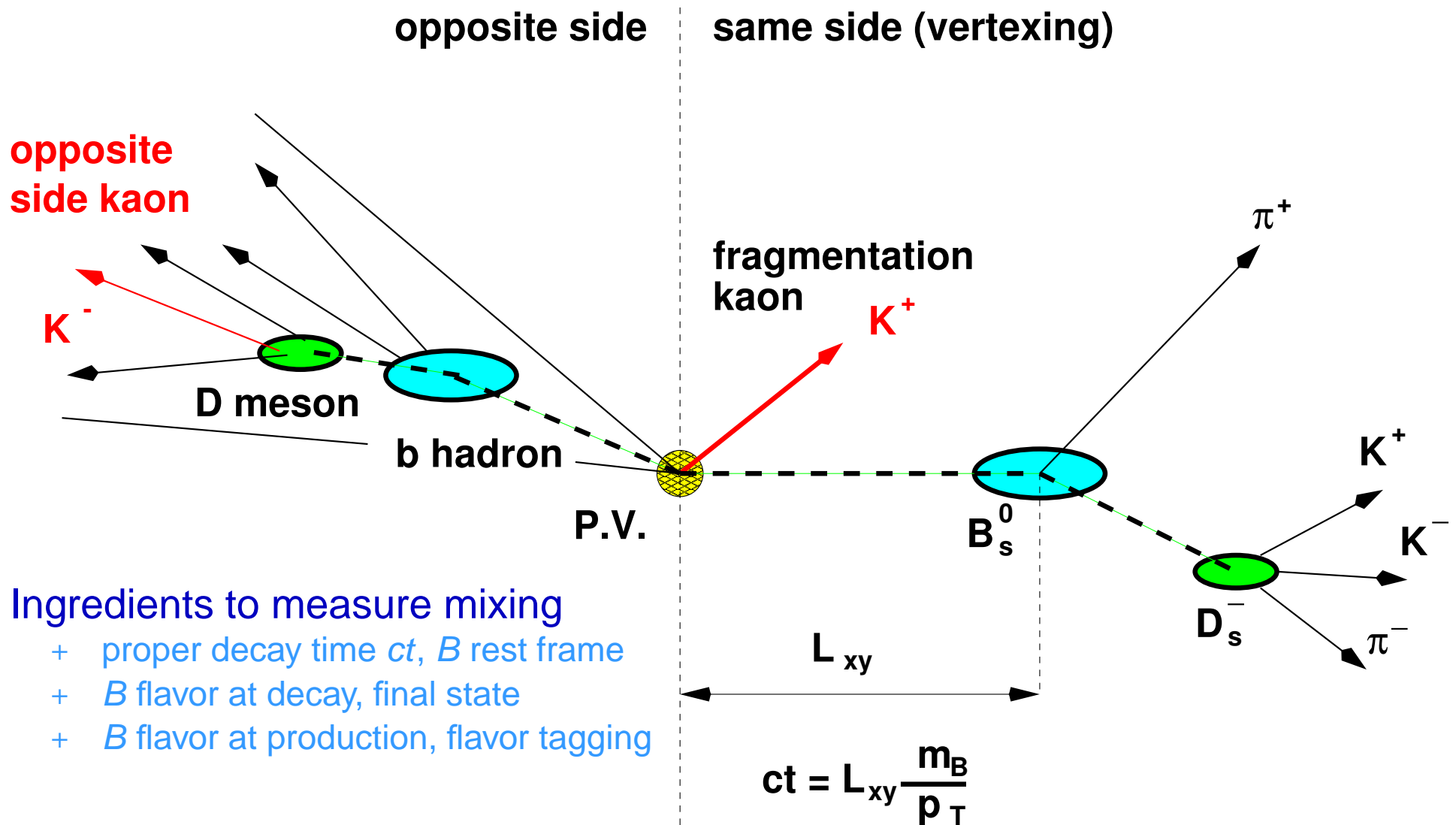
$$P(t)_{B^0 \rightarrow B^0} = \frac{1}{2\tau} e^{-t/\tau} (1 + \cos \Delta m t)$$

τ is the B^0 -meson lifetime

Measure oscillation frequency: Δm

also $x = \Delta m/\Gamma$

B_s Mixing: Experimental Ingredients



Measure time dependent asymmetry

$$A_0(t)_{(meas)} \equiv \frac{N(t)_{RS} - N(t)_{WS}}{N(t)_{RS} + N(t)_{WS}} = D \cos(\Delta m_s t)$$

Why is that so difficult?

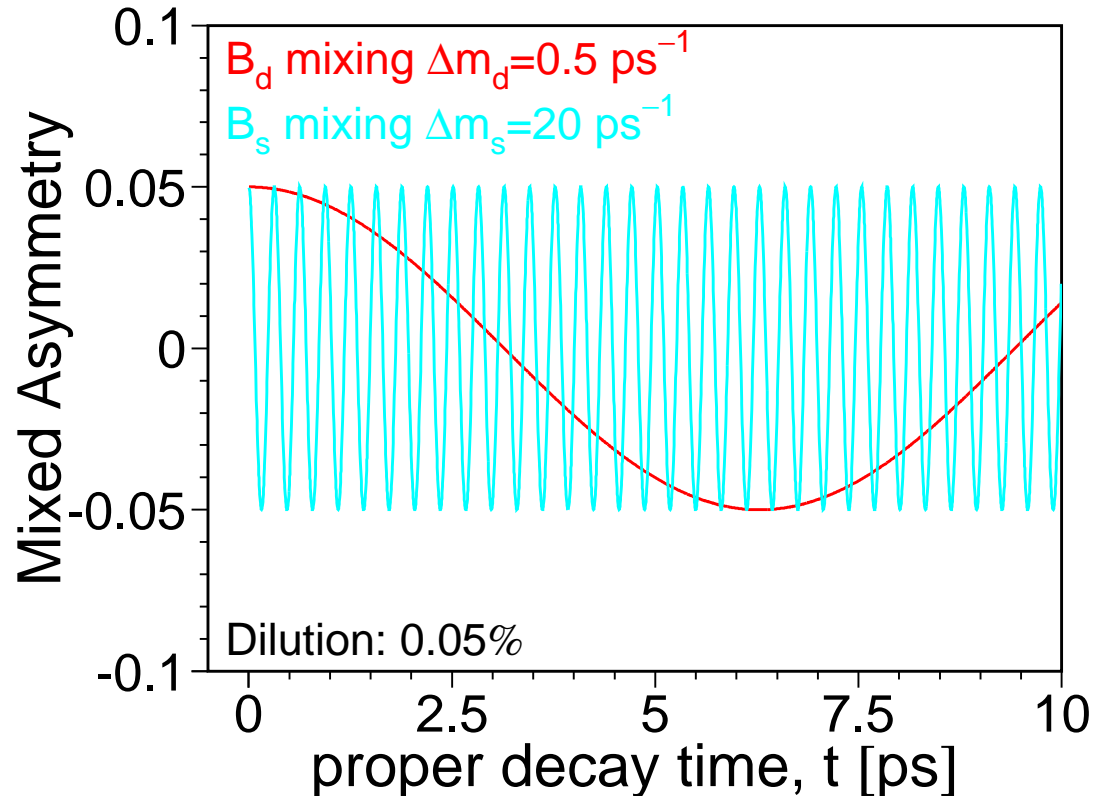
B_s mixing

+ very fast

Challenge

- + precise vertex
- + precise momentum
- + many events
- + tagging essential

Very tricky!



Where are we so far?

- + established momentum and vertex resolution
- + started on the tagging
- + established signal and details of signal composition
- + make interesting measurements along the way

Momentum Scale Calibration

First measurements

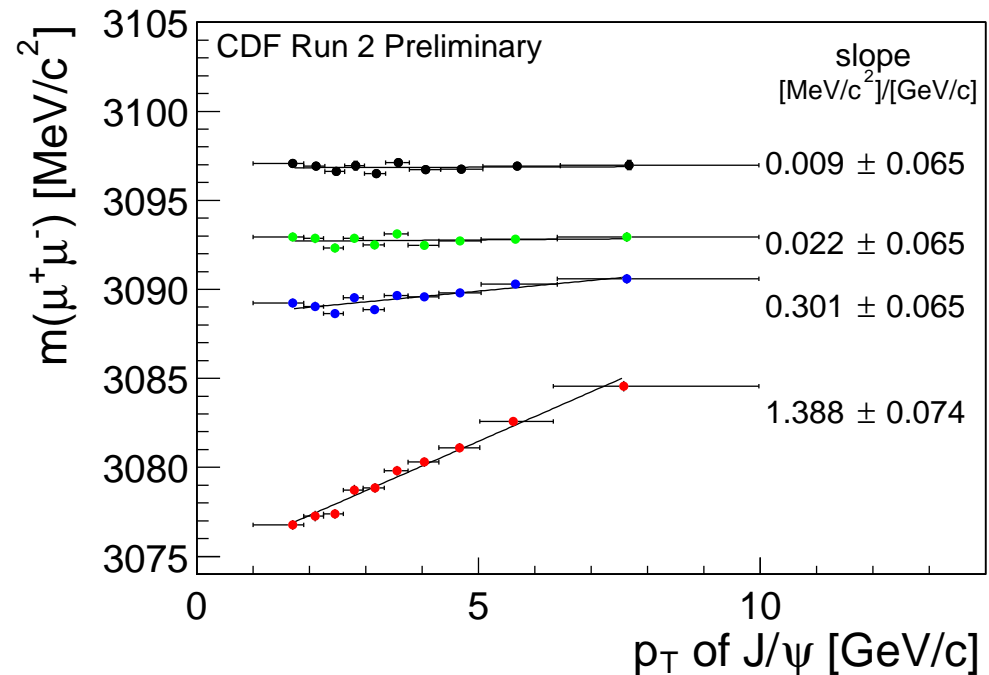
- + mass: B^0 , B^+ , B_s , Λ_b
- + mass difference: $m_{D_s} - m_{D^+}$
- + lifetimes: inclusive, exclusive

Next measurements

- + hadronic branching ratios
- + B^0 mixing (taggers under way)
- + excellent prep for B_s mixing

Calibration of the tracking

- + use: $J/\psi \rightarrow \mu^+\mu^-$ (500k)
- + measure material in detector
- + measure momentum scale
→ adjust B field
- + new method invented by MIT
- + more sophisticated than Run I
- + first blessed Run II analysis



Calibration procedure

- + raw tracks
- + nominal E loss corrections
- + fine tuned E loss corrections
- + adjust overall scale (B field)

D Meson Mass Difference - First Tevatron Publication

Conceptual idea

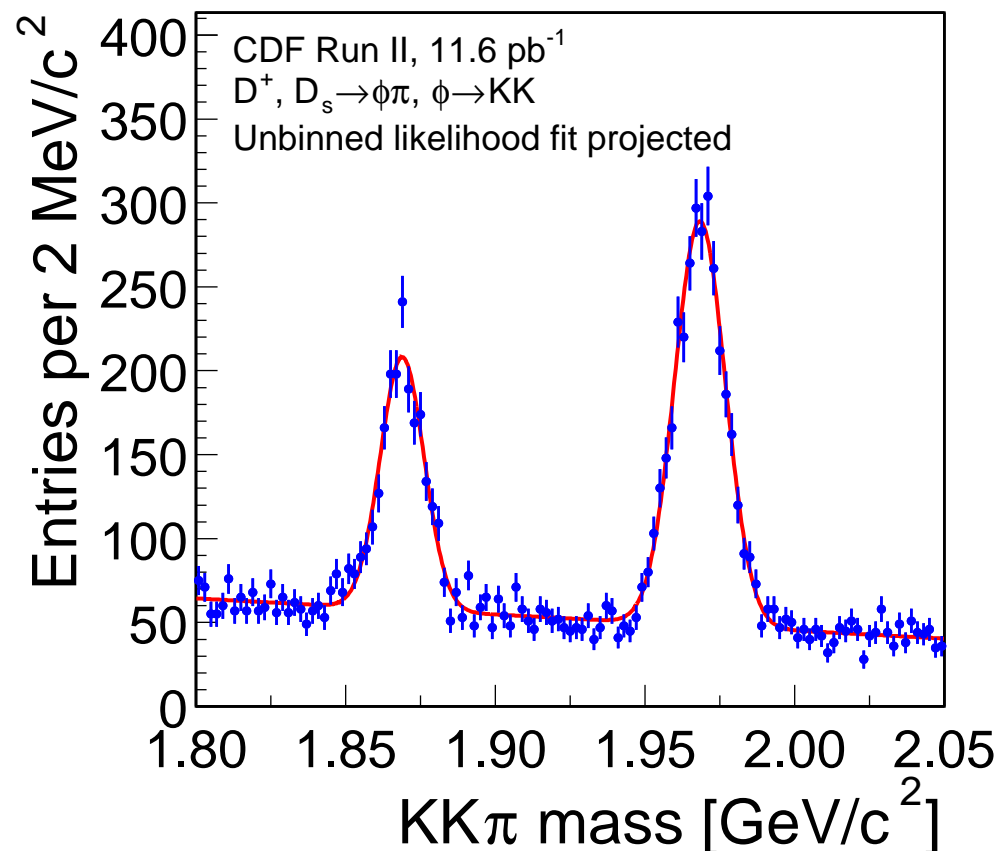
- + $D_s^+ \rightarrow \phi \pi^+ (\phi \rightarrow K^+ K^-)$
- + $D^+ \rightarrow \phi \pi^+ (\phi \rightarrow K^+ K^-)$
- + almost identical kinematics
- + measure difference
- + basically no systematics

Result $m(D_s^+) - m(D^+)$:

$$99.41 \pm 0.38_{\text{(stat)}} \pm 0.21_{\text{(syst)}} \text{ MeV}/c^2$$

About the measurement

- + first Tevatron publication
- + uses new SVT trigger
- + agrees with old world average
 $99.5 \pm 0.50 \text{ MeV}/c^2$



Recent BaBar:

PRD 65(2002)091104

$$98.4 \pm 0.1_{\text{(stat)}} \pm 0.3_{\text{(syst)}} \text{ MeV}/c^2$$

B Hadron Masses - World Best Measurements

Largest J/ψ modes

- + $B^+ \rightarrow J/\psi K^+$
- + $B^0 \rightarrow J/\psi K^{*0}, B^0 \rightarrow J/\psi K_S^0$
- + $B_S^0 \rightarrow J/\psi \phi$
- + $\Lambda_b^0 \rightarrow J/\psi \Lambda$

B meson masses in MeV/c^2

already blessed

$$B^+ : 5279.32 \pm 0.68 \text{ (stat)} \pm 0.94 \text{ (sys)}$$

$$B^0 : 5280.30 \pm 0.92 \text{ (stat)} \pm 0.92 \text{ (sys)}$$

$$B_S^0 : 5365.5 \pm 1.3 \text{ (stat)} \pm 0.94 \text{ (sys)}$$

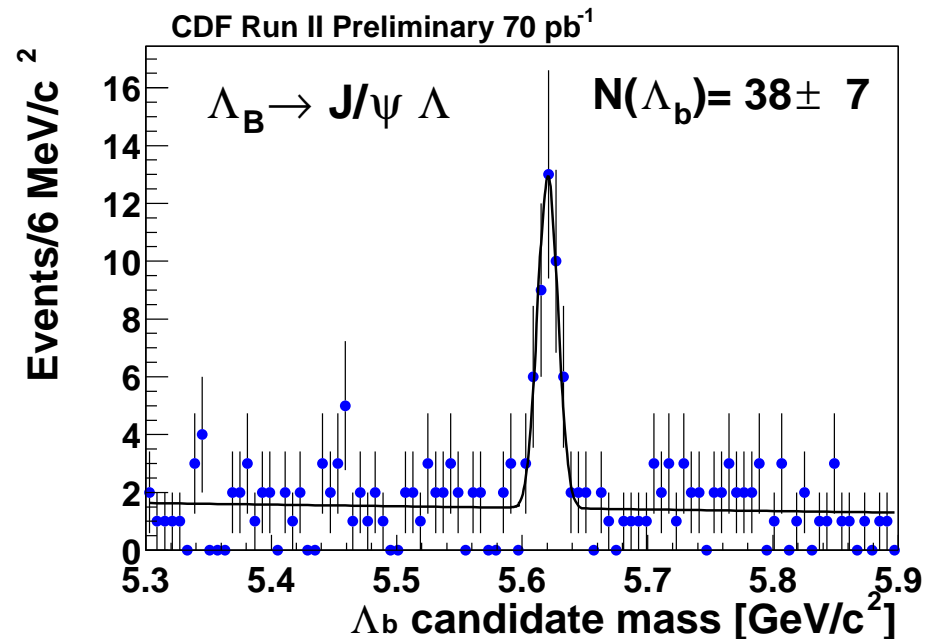
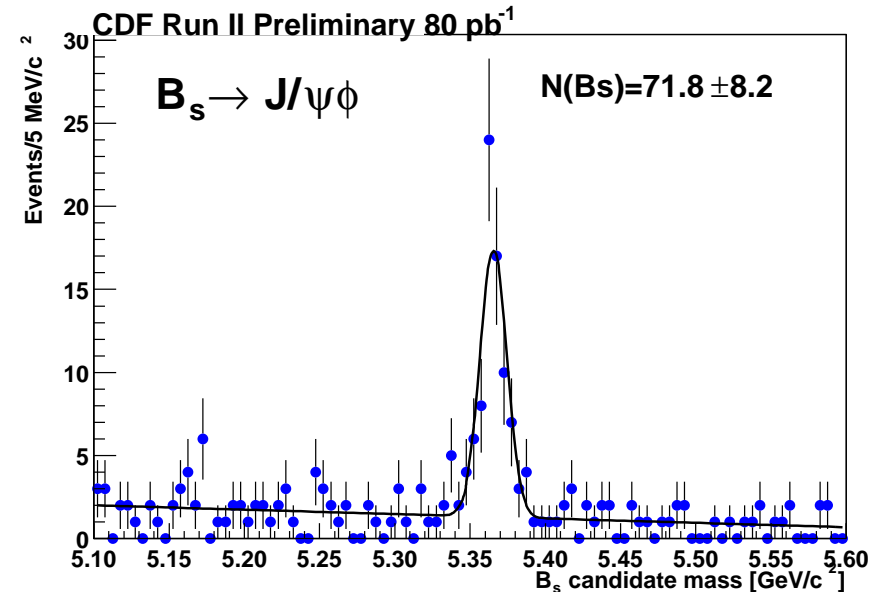
$$B^0 : 5281.54 \pm 0.80 \text{ (stat)} \pm 1.2 \text{ (sys)}$$

$$\Lambda_b^0 : 5620.4 \pm 1.6 \text{ (stat)} \pm 1.2 \text{ (sys)}$$

publishing soon!!

CDF Momentum scale

- + best B_S^0 and Λ_b^0 in the world
- + best systematic around ..
- + excellent prerequisite



B Hadron Lifetimes from MIT

Large sample of $J/\psi \rightarrow \mu^+\mu^-$ events

- + calibrate resolution
- + understand alignment
- + measure inclusive B lifetime
- + so far only r - ϕ silicon used

Inclusive J/ψ (blessed)

$$c\tau_{incl} = 458 \pm 10_{(stat)} \pm 11_{(sys)} \mu\text{m}$$

Exclusive J/ψ (blessed)

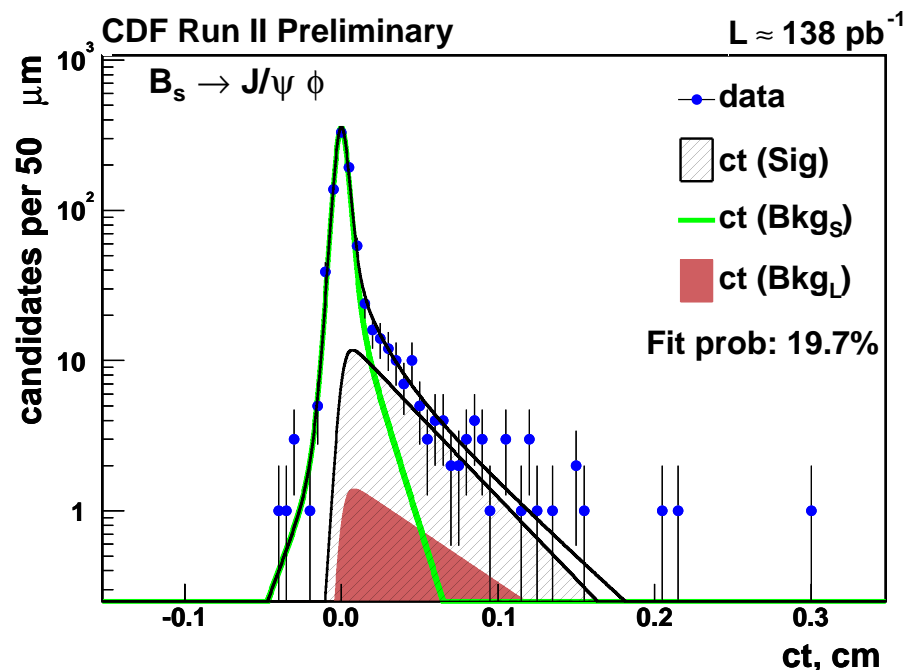
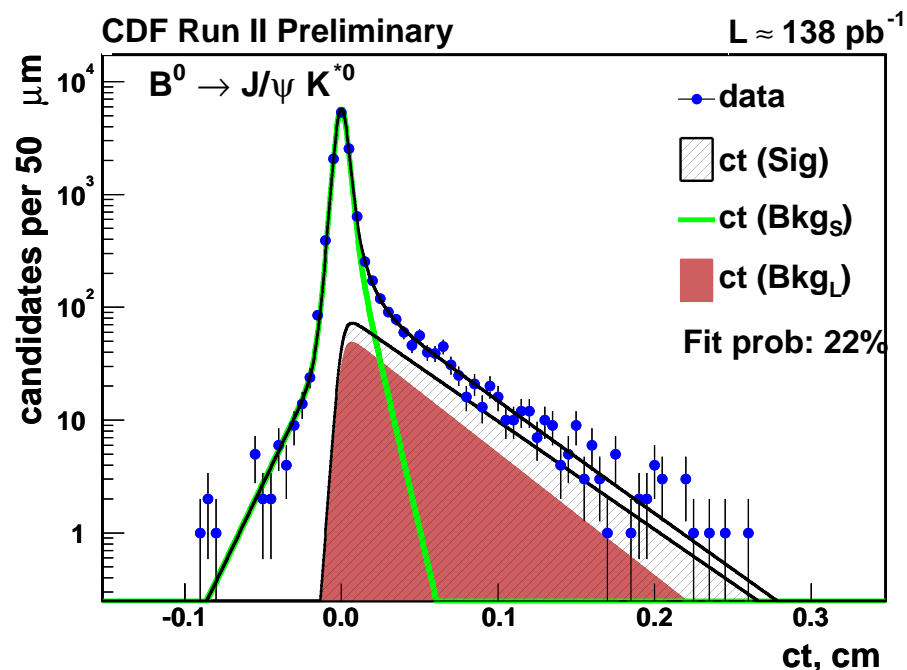
$$c\tau_{B^+} = 490 \pm 15_{(stat)} \pm 11_{(sys)} \mu\text{m}$$

$$c\tau_{B^0} = 453 \pm 19_{(stat)} \pm 6_{(sys)} \mu\text{m}$$

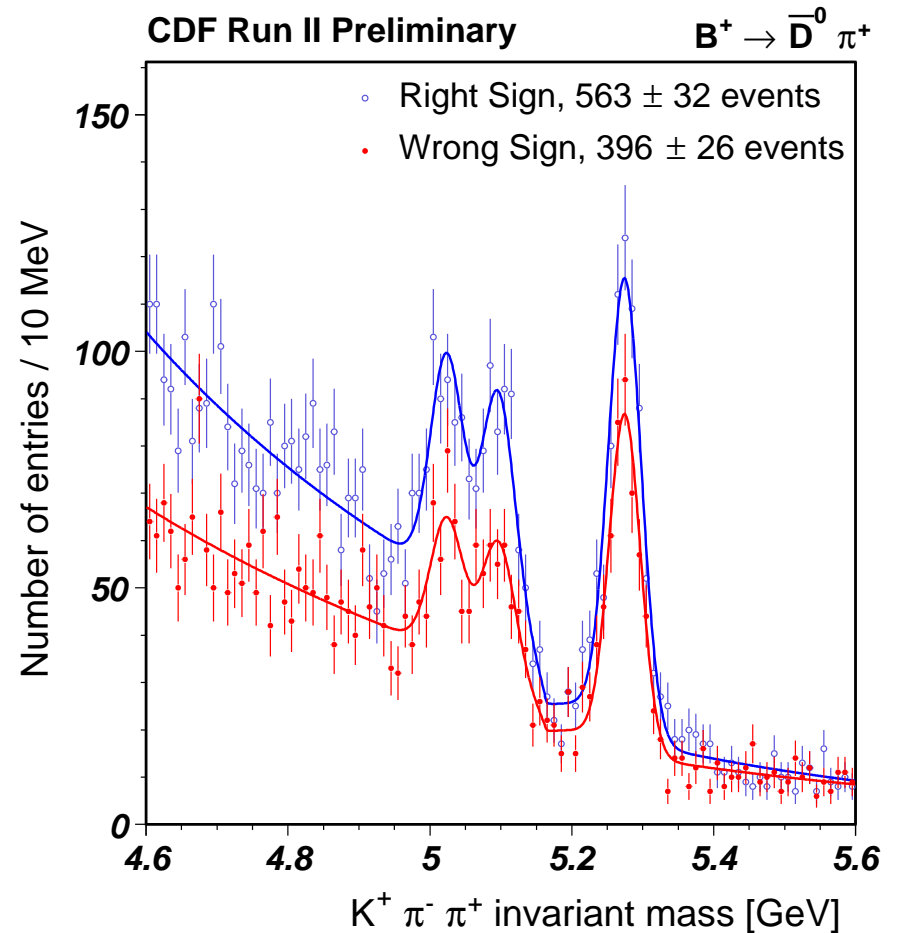
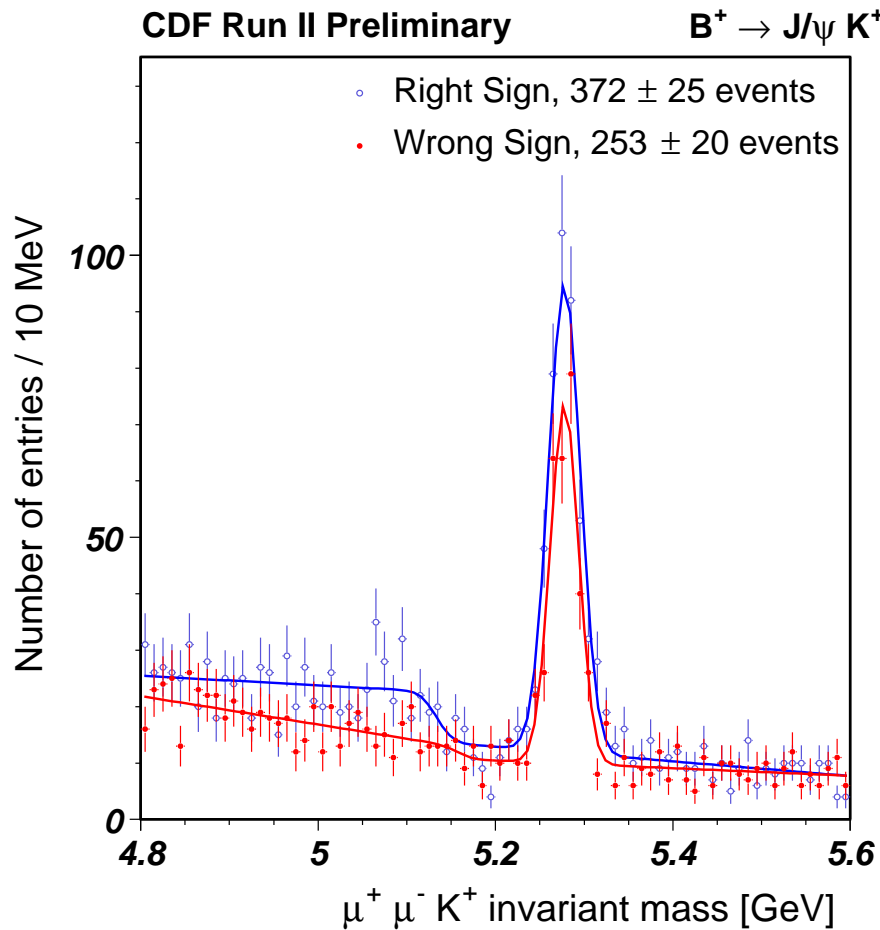
$$c\tau_{B_s^0} = 399 \pm 43_{(stat)} \pm 6_{(sys)} \mu\text{m}$$

About results

- + silicon already well understood
- + prerequisite for $\Delta\Gamma_s$
- + major improvements expected:
Layer 00, 3D tracking, alignments
- + important for B_s mixing



Tagging Preparations



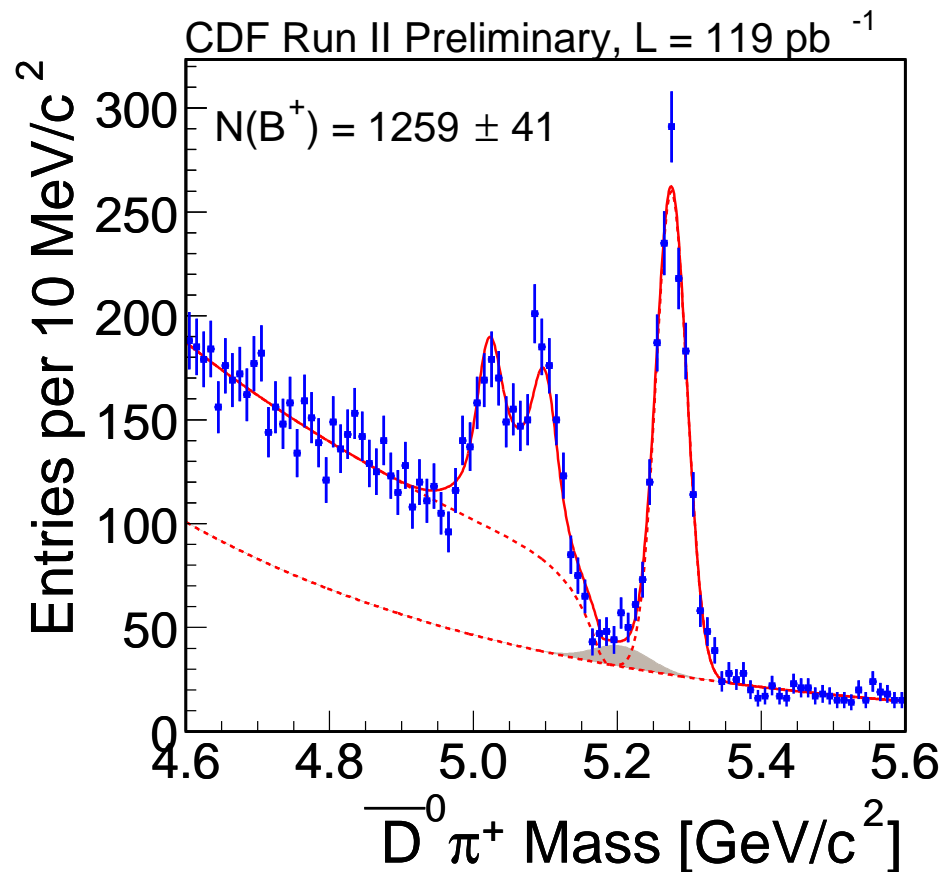
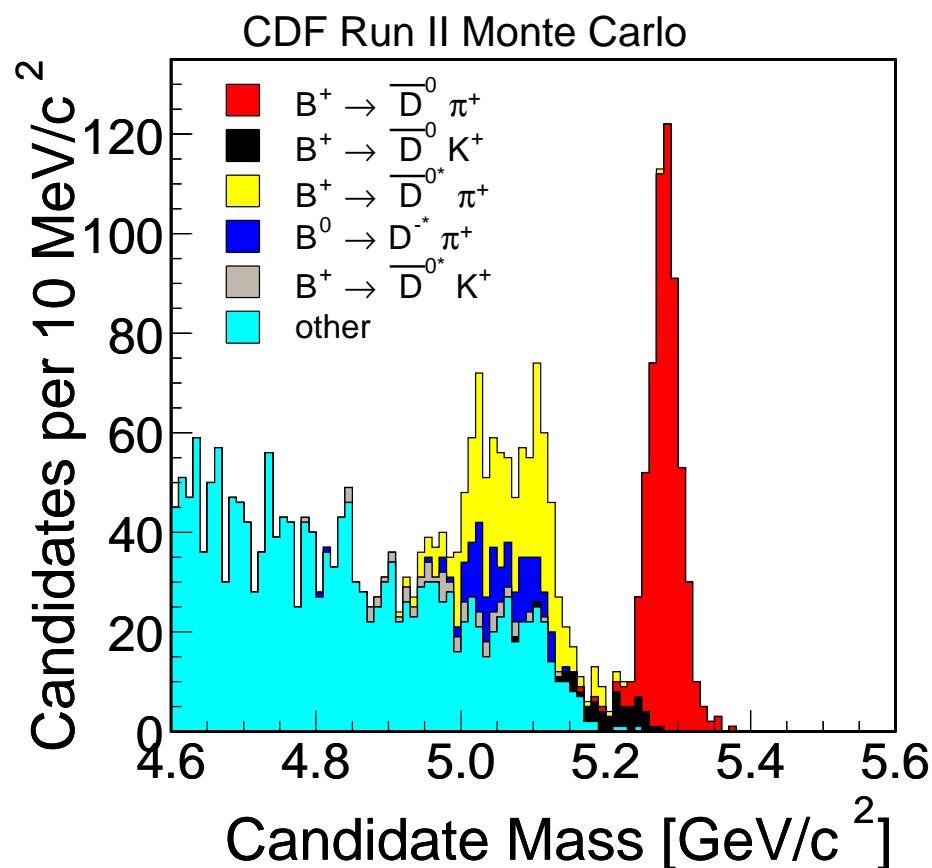
Decent samples of fully reconstructed B^+

first study of same side pion tagger in Run II:

$J/\psi K$: $\epsilon D^2 = (2.4 \pm 1.2)\%$; $D^0 \pi$: $\epsilon D^2 = (1.9 \pm 0.9)\%$

compares well with Run I, B^0 mixing measurement under way

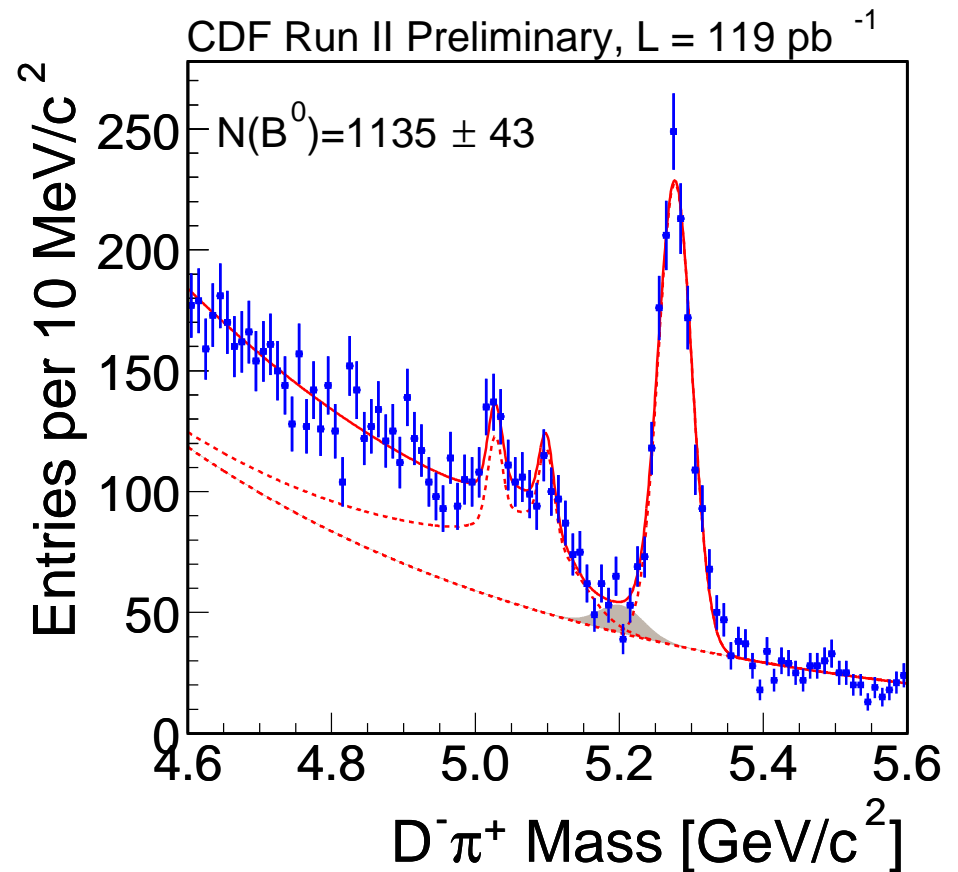
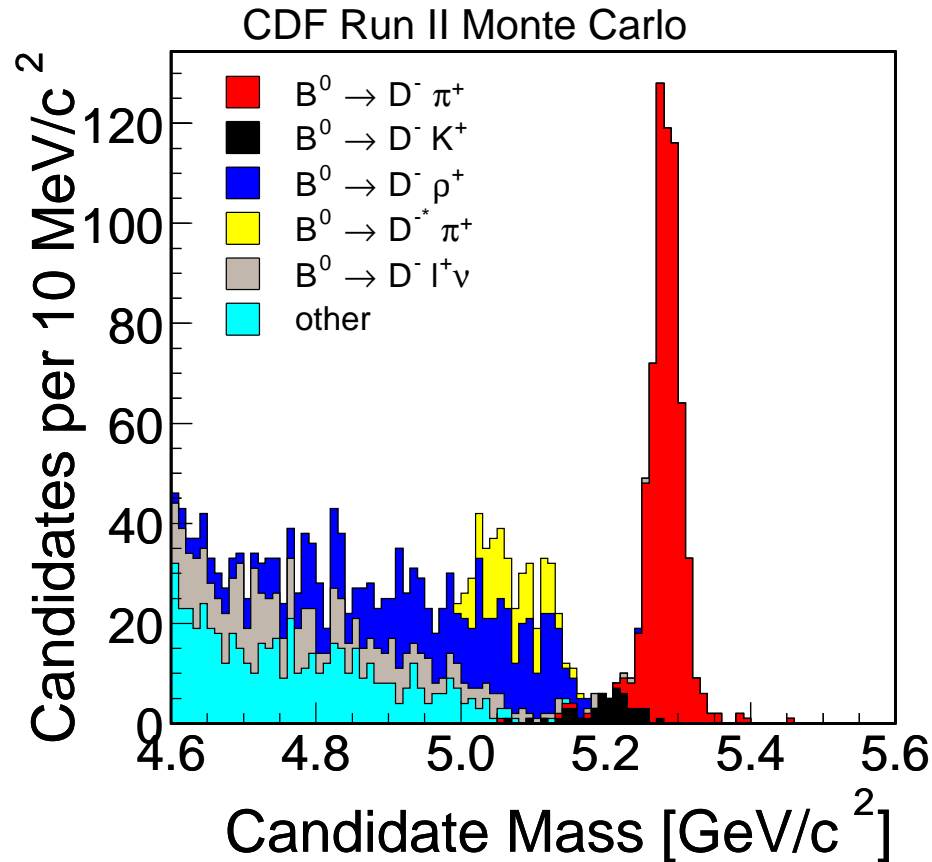
Reconstruct Exclusive Hadronic Decays



Reconstruct $B^+ \rightarrow \bar{D}^0 \pi^+$

- + first time at a hadron machine, very clean
- + very large calibration signal, precise test for reflections
- + serves as normalization channel for rate measurements

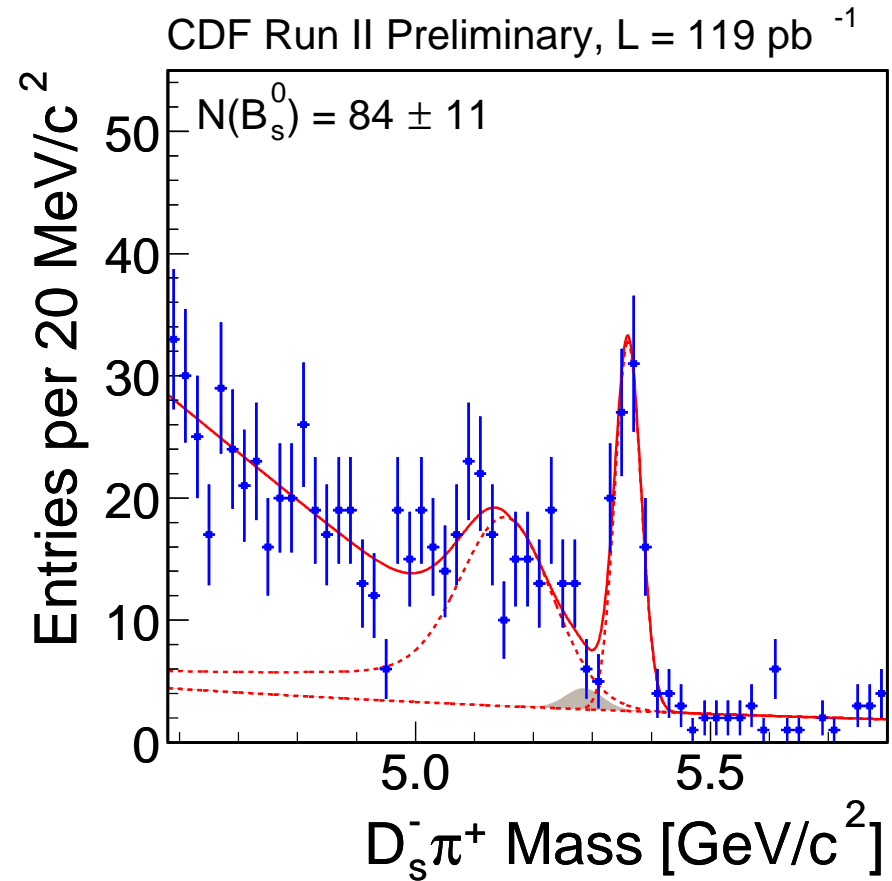
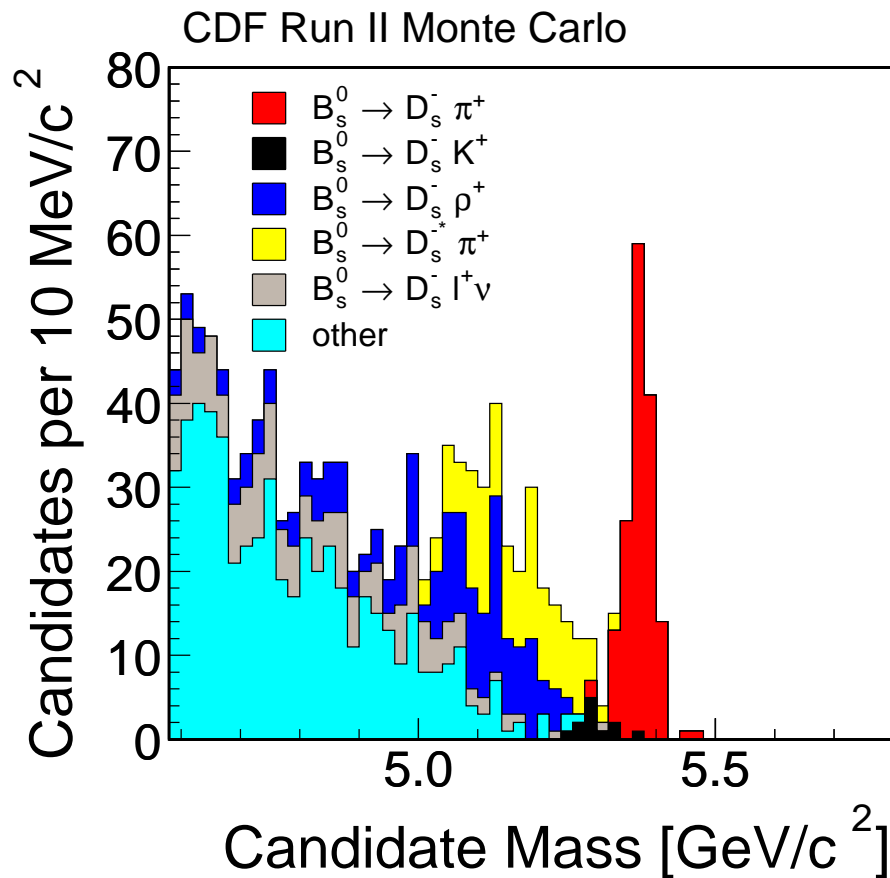
Reconstruct Exclusive Hadronic Decays



Reconstruct $B^0 \rightarrow D^- \pi^+$

- + practically identical to $B_s^0 \rightarrow D_s^- \pi^+$
- + most systematics for rate measurements cancel
- + again reflections very well described

First Time Observation



Reconstruct $B_s^0 \rightarrow D_s^- \pi^+$ ($D_s^- \rightarrow \phi \pi^-$) – unique at CDF

$$\frac{f_s Br(B_s \rightarrow D_s^- \pi^+)}{f_d Br(B^0 \rightarrow D^- \pi^+)} = 0.35 \pm 0.05(stat) \pm 0.04(syst) \pm 0.09(BR)$$

+ result is being published (less events than hoped for)

CDF Flagship Analysis: B_s Mixing

Summary

- + B_s mixing unique at Tevatron
- + one side of unitarity triangle
- + complements B factories
- + more difficult than anticipated

Baseline

- + 500/pb: 2σ at $\Delta m_s = 15^{-1}$ ps (world best limit)

Modest improvements

- + 1.7/fb: 5σ at $\Delta m_s = 18^{-1}$ ps (SM prediction)
- + 3.2/fb: 5σ at $\Delta m_s = 24^{-1}$ ps (complete SM prediction)

Work aggressively to improve

Topics of studies

- + more events at a given luminosity (trigger)
- + improve vertex resolution
- + enhance flavor tagging (improve TOF reconstruction)

Recent Surprise in Spectroscopy

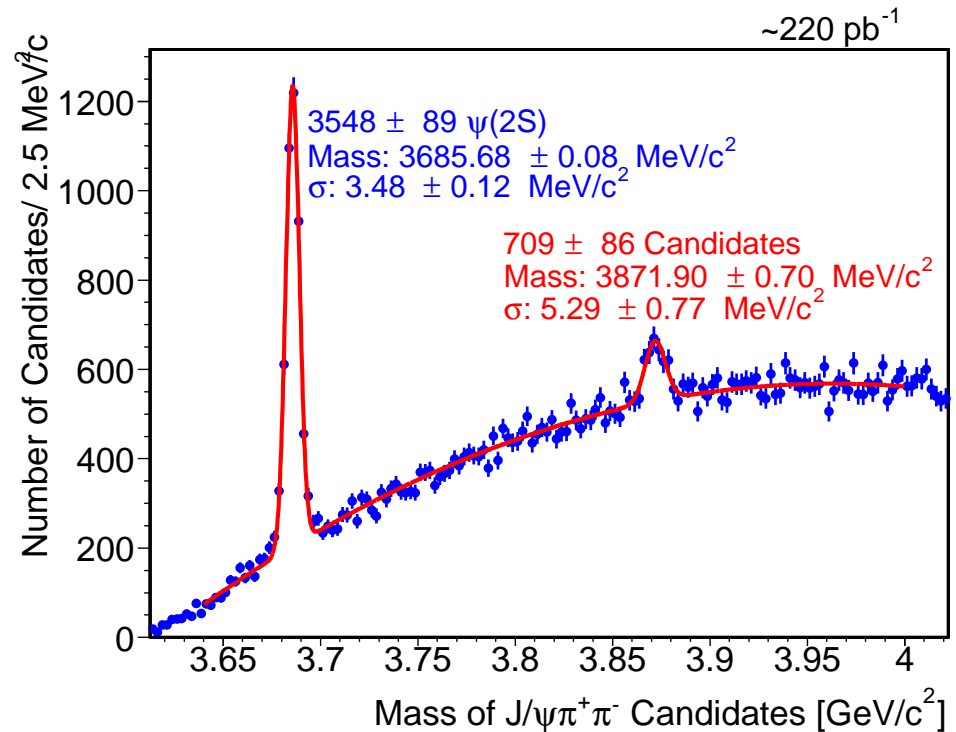
Belle observes narrow state

- + final state $J/\psi\pi^+\pi^-$
- + exclusive: $B^+ \rightarrow J/\psi\pi^+\pi^-K^+$
- + 35.7 ± 6.8 events
- + possibly charmonium
- + mass is unexpected
- + shown August 12, 2003

CDF confirms September 20

- + final state $J/\psi\pi^+\pi^-$
- + mostly prompt production
- + $\bar{p}p$ different initial state
- + 709 ± 86 events

CDF response is
very prompt
competitive
complementary



Mass measured by CDF:

$3871.4 \pm 0.7 \pm 0.4 \text{ MeV}/c^2$

Compares well with Belle:

$3872.0 \pm 0.6 \pm 0.5 \text{ MeV}/c^2$

CKM Parameter: Angle γ

Use $B \rightarrow hh'$

- + γ of unitarity triangle
- + decompose:
 $B_{d,s} \rightarrow K\pi$, $B_d \rightarrow \pi\pi$, $B_s \rightarrow KK$
- + determine penguin pollution
- + 'model independent' γ
- + complementary to BaBar/Belle
- + would you have believed that?

Need more statistic:

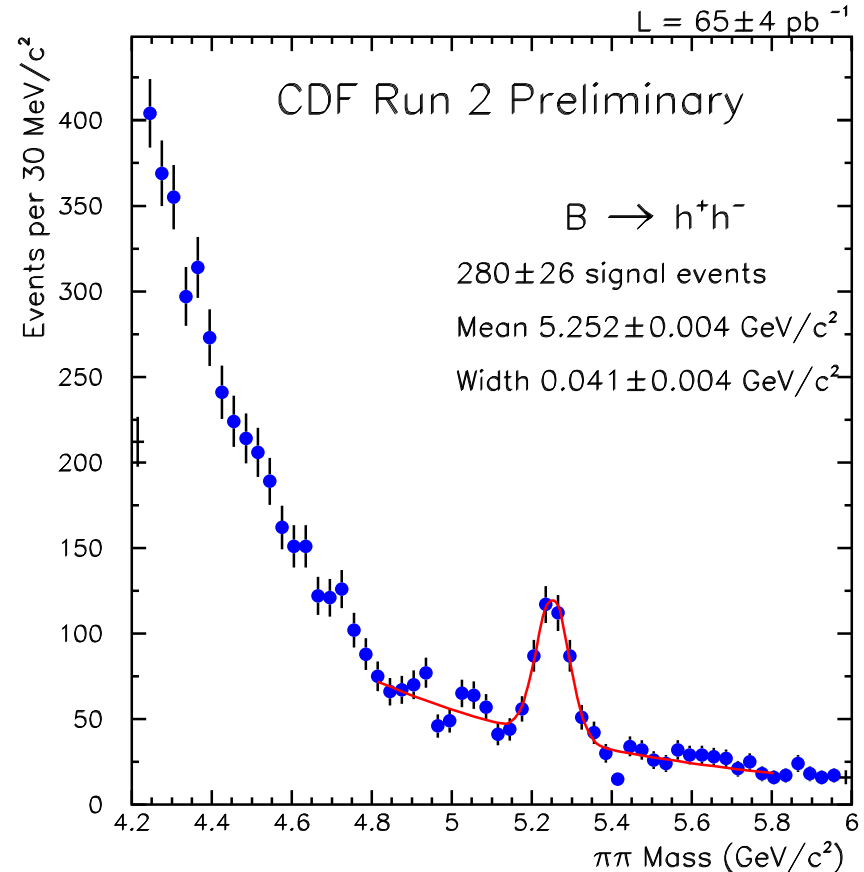
bandwidth/luminosity

CDF potential

proven

competitive

complementary



Significant $B_s \rightarrow K^+K^-$ observed:

$$\frac{f_s Br(B_s \rightarrow KK)}{f_d Br(B^0 \rightarrow K\pi)} = 0.74 \pm 0.20 \pm 0.22$$

$$\text{Measure } A_{CP} = \frac{N(\bar{B} \rightarrow K^- \pi^+) - N(B \rightarrow K^+ \pi^-)}{N(\bar{B} \rightarrow K^- \pi^+) + N(B \rightarrow K^+ \pi^-)}$$

$$0.02 \pm 0.15 \pm 0.02$$

Summary

B physics at CDF ($p\bar{p}$ machine)

- + is complementary to the B factories
- + can compete even in some common aspects

B_s mixing unique at Tevatron

- + more difficult than expected
- + .. but it is doable, first results by summer
- + preparations are going very well
- + a lot of additional handles to work on

Doing good physics meanwhile

- + mass measurements, lifetime ratios and $\Delta\Gamma_s$
- + branching ratio measurements
- + spectroscopy: onia, exotics (penta/tetra quarks etc.)